Appendix G. The Cumulative Watershed Effects Temperature Model Applied to the South Fork Clearwater River Subbasin

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The Cumulative Watershed Effects Temperature Model Applied to the South Fork Clearwater River Subbasin

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For the South Fork Clearwater River (SF CWR) Subbasin assessment and total maximum daily load (TMDL), streams were divided into two categories for temperature analysis: 1) those that still retain a reasonable semblage of the natural forest canopy and are primarily managed for forestry and/or natural vegetative conditions, and 2) those where the natural vegetation has been greatly altered by grazing, agriculture, mining, and road building. This later category includes all of the main stem SF CWR. Those lands primarily managed for forestry are being analyzed using a method developed under Idaho's Forest Practices Act (FPA) (IDL 2000), and all the others are being analyzed using a method developed by the U.S. Environmental Protection Agency (USEPA) based on the system's potential vegetation (Appendix F). In both cases, vegetative shading is the primary factor being analyzed as the parameter affecting stream temperature. This appendix describes the FPA Cumulative Watershed Effects (CWE) temperature model as it was applied for the forested portions of the SF CWR Subbasin.

Background

The six modes of heat transfer important in stream temperature analyses are (Adams and Sullivan 1990):

- Solar radiation (short wave)
- Radiation between the stream and the adjacent vegetation and sky (long wave)
- Evaporation from the stream
- Convection between the stream and the air
- Conduction between the stream and the streambed
- Ground water and tributary mass inflow/outflow

There are process-based stream temperature models such as Heat Source (Boyd 1996) or SSTEMP (Theurer et al. 1984, Bartholow 1997) for analyzing stream temperatures by quantifying the heat transfer processes. However, these models tend to require extensive inputs, many of which are not easily available or reliable for remote, mountain streams. The relative importance of each mode of heat transfer varies according to the specific environmental conditions present from reach to reach.

Analyses have established that the primary environmental factors affecting stream temperature are local air temperature, stream depth, ground water inflow, and the extent to which riparian canopy and topography shade the stream (Sullivan and Adams 1990, Theurer et al. 1984, Beschta and Weatherred 1984). In forested environments with small first and second order streams, stream shading and local air temperature are widely recognized as the major environmental determinants of stream temperature, accounting for up to 90% of stream

temperature variability (Brown 1971, IDL 2000). Stream shading is also the primary factor that has been modified by human activities. The Idaho water quality standards for temperature apply only to characteristics that may vary due to human activities.
The Idaho Forest Practices Act Coordinating Committee (IDL 2000) developed an empirical model of stream temperatures in forested environments in Idaho north of the Salmon River based on continuous water temperature measurements, elevation, and percent canopy cover data. The model is identified as the Cumulative Watershed Effects (CWE) temperature model and is represented by the following equation:

$$MWMT = 29.1 - 0.00262\ E - 0.0849\ C$$

where MWMT = maximum weekly maximum temperature (^oC)
E = stream reach elevation (feet)
C = riparian canopy closure (%)

Data for this model were collected throughout north Idaho. The model utilizes percent stream canopy closure and elevation to predict the maximum weekly mean maximum stream temperature (the MWMT of the hottest week of the year). Elevation and percent canopy closure are easy to acquire: elevation from topographic maps and percent canopy closure from aerial photography correlated to percent canopy closure collected using a densiometer. In mountainous terrain such as the SF CWR Subbasin, increases in elevation result in reductions in ambient air temperature, thus reducing heat loading in a predictable manner. In addition, increases in shading decrease heat loading by reducing solar insolation impinging on the water surface and by lowering the local air temperature under the canopy. The utility of the CWE temperature model is that it can be solved for percent canopy closure, the major environmental factor that changes as a result of human activity.

The following is quoted from the *Forest Practices Cumulative Watershed Effects Process for Idaho* (IDL 2000) pp C-3 and C-4:

> The shade-elevation/temperature relationships used in this section were developed from data collected throughout Idaho between 1991 and 1998. Two hundred and forty-six data sets have been analyzed to develop shade-elevation/temperature relationships for both northern and southern Idaho with R-square values of 0.58 and 0.71, respectively.
>
> The shade-elevation/temperature relationship has been validated in Washington State (Sullivan and Adams 1990). In that study, a simple temperature screen based on elevation and canopy closure over the stream correctly identified the temperature category according to Washington water quality criteria 89% of the time. A temperature screen specific to eastern Washington (CMER, 1993) accurately predicted the necessary level of canopy cover at 69% of locations, with most errors leading to conservative predictions.

Idaho has the following water temperature standards, reflecting the needs of different beneficial uses in streams:

1) Cold Water Biota (22°C instantaneous maximum and 19°C maximum daily average) - Applies to all streams in the state throughout the year.
2) Salmonid Spawning (13°C instantaneous maximum and 9°C maximum daily average) - Applies to streams with salmonids (trout, salmon, char and whitefish) present during the spawning and incubation period.
3) Bull Trout (12°C daily average during June, July and August and 9°C daily average during September and October) - Applies to streams where spawning or rearing bull trout occur.

Using different methodologies (instantaneous maximums and maximum daily averages) to evaluate Idaho stream temperature standards makes this process confusing and difficult. To simplify this approach, the CWE process evaluates all temperature standards using one methodology--a rolling 7-day average of daily maximum temperatures, otherwise known as the maximum weekly maximum temperature (MWMT). The MWMT is chosen for several reasons. First, instantaneous maximums can be short in duration and may not represent the impact stream temperature will have on fish, especially if significant cooling occurs soon after the peak temperature. Second, the daily average does not allow evaluation of peak temperatures and can mask large fluctuations around the mean. Greater fluctuation around the mean can be one effect of intensive forest canopy management, and can negatively influence fish. Finally, MWMT is consistent with other temperature criteria that have been established or recommended to protect bull trout and other fish species (ODEQ 1995; USDA Forest Service 1995; USEPA 1997; Sugden et. al., 1998).

The conversion of Idaho's stream temperature standards to MWMT is show below. These conversions were accomplished using formulas developed by Sugden et al. (1998) in their analysis of 220 different stream temperature data sets collected in Northern Idaho and Western Montana between 1991 and 1997.

Cold Water Biota
22°C instantaneous max = 21.01°C MWMT
19°C daily average = 21.75°C MWMT

Salmonid Spawning
13°C instantaneous maximum = 12.36°C MWMT
9°C daily average = 9.70°C MWMT

Bull Trout
12°C daily average (June, July and August) = 13.31°C MWMT
9°C daily average (September and October) = 9.7°C MWMT

Methods

Using the conversion factor developed by Sugden et al. (1998) for northern Idaho and western Montana, a 9^{o}C (48.2^{o}F) daily average temperature is equivalent to a 9.7^{o}C (49.5^{o}F) MWMT. This means that the federal bull trout temperature standard and Idaho's salmonid spawning standard are roughly equivalent in terms of MWMT. We assume they are equivalent and use a 10^{o}C (50^{o}F) MWMT for both standards in our calculations below.

In terms of timing, heat loading in the SF CWR Subbasin is at its greatest during late July and early August and is reflected in the higher stream temperatures at this time (see temperature discussion in Chapter 2 and temperature plots in Appendix J). July and August are the critical months for temperature exceedances. Water temperatures begin to increase through May and June, but are consistently at their peaks during late July and early August. Water temperatures decrease rapidly after the first wet cold fronts of late August or early September. The time periods for which the standards apply are dependent on the salmonid species spawning and incubation times in the particular water body. The spawning time periods for the different salmonid species in the SF CWR Subbasin are presented Appendix D, Attachment D-1. The salmonid species known to be present in the different water bodies of the SF CWR Subbasin are presented in Appendix D, Tables D-1, D-2 and D-11, and Figures D-9 through D-17.

The CWE process analyzes heat loading and stream temperature for the critical period of late July through early August since the data used to develop the model were collected in this time period. Application of the process assumes that if stream temperatures are in compliance with the water quality standards during this period, they will be in compliance throughout the rest of the year.

The stream temperature data in Table J-1 (Appendix J) show the stream temperatures for one location in the water body. These data were usually collected near the mouth of the stream where temperatures are likely to be the highest. They give some idea of the overall magnitude of heat loading to the water body, but provide little information about where in the water body heat is gained. Since water quality standards apply throughout a water body, it is necessary to understand heat loading throughout a water body.

Solar insolation at some reference elevation over the whole of a water body can be assumed to be constant at any given moment (i.e., there is no spatial variation in solar insolation at the scale of a water body). Spatial variation of heat loading to a stream is largely a function of how solar insolation interacts with a stream and its immediate surroundings. In forested environments, the major component of this interaction is the amount of shade reducing direct solar insolation on the water surface and/or other surfaces in the immediate environment of the stream. The CWE temperature model predicts the spatial distribution of heat loading throughout a water body based on elevation and the percent canopy closure over the stream.

The CWE temperature analysis method throughout a water body is straightforward. The majority of the data are gathered using aerial photographs and topographic maps and/or a geographical information system (GIS). All the perennial streams are divided into 200-foot elevational reaches (i.e., any given analysis reach can have a maximum of 200 feet difference in elevation between its lower end and upper end). Reaches are also broken at perennial stream intersections and at points where there is a major change in canopy closure along the reach. This process resulted in over 3,500 reaches identified for the SF CWR Subbasin.

The stream segments are identified in the GIS such that each stream segment can be located on a map. For each stream segment, several data types are established: the elevation at the lower end of the reach, the current percent canopy closure from aerial photo interpretation, and general orientation of the stream reach. Using maps and information about salmonid distribution such as those presented in Appendix D and Appendix J, each reach is classified according to the level of beneficial uses it should support. From these data, the CWE model is run to predict the percent canopy closure needed to protect stream temperatures for the desired beneficial use.

Under the FPA-developed CWE process, the target percent canopy closure to protect beneficial uses is that calculated by the model. Any required percent canopy closure increase is determined by subtracting the existing percent canopy closure from the CWE model targeted percent canopy closure, resulting in a CWE target percent canopy closure increase. If the current canopy is greater than the target canopy, then no canopy closure increase is required.

However, in the interest of building further stream temperature protection into the TMDL process, USEPA Region 10 has determined that no percent canopy closure target should be set at less than the current percent canopy closure (Psyk 2001). In other words, when the CWE temperature model is used to set targets for a TMDL, the target canopy is to be either the CWE-modeled percent canopy closure, or the current percent canopy closure, whichever is greater.

CWE Temperature Model Results for SF CWR Subbasin

The targets by stream segment are presented in graphic form on a map and in an associated table. The ArcView shapefiles containing the graphics and target allocation data are on the diskette included with this document.

Using the CWE process, we analyzed the current shade condition of 3,500+ stream reaches in the 82 watersheds for which TMDLs are being developed. Existing percent canopy closures as determined by the CWE methods are presented in Figures G-1 through G-3. Figure G-1 shows the existing shade for the whole subbasin, except the Cottonwood Creek watershed. Figures G-2 and G-3 show the existing shade for the Threemile and Butcher Creek areas, and the area around Little and Big Elk Creeks. We selected these two areas to show at a larger scale because they are the 303(d) listed areas of interest. Parts of the middle reaches of Threemile Creek and Butcher Creek were not assessed for lack of aerial photos. The TMDL for these areas uses the System Potential Vegetation (SPV) methods.

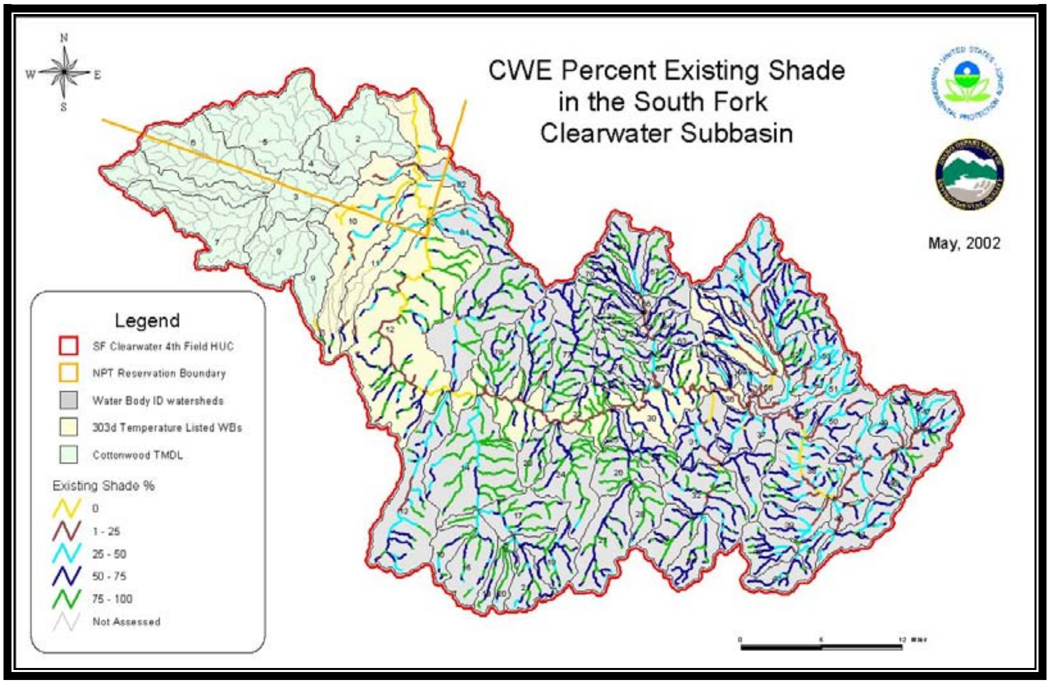

Figure G-1. Current Percent Canopy Closure Over Streams in the SF CWR Subbasin

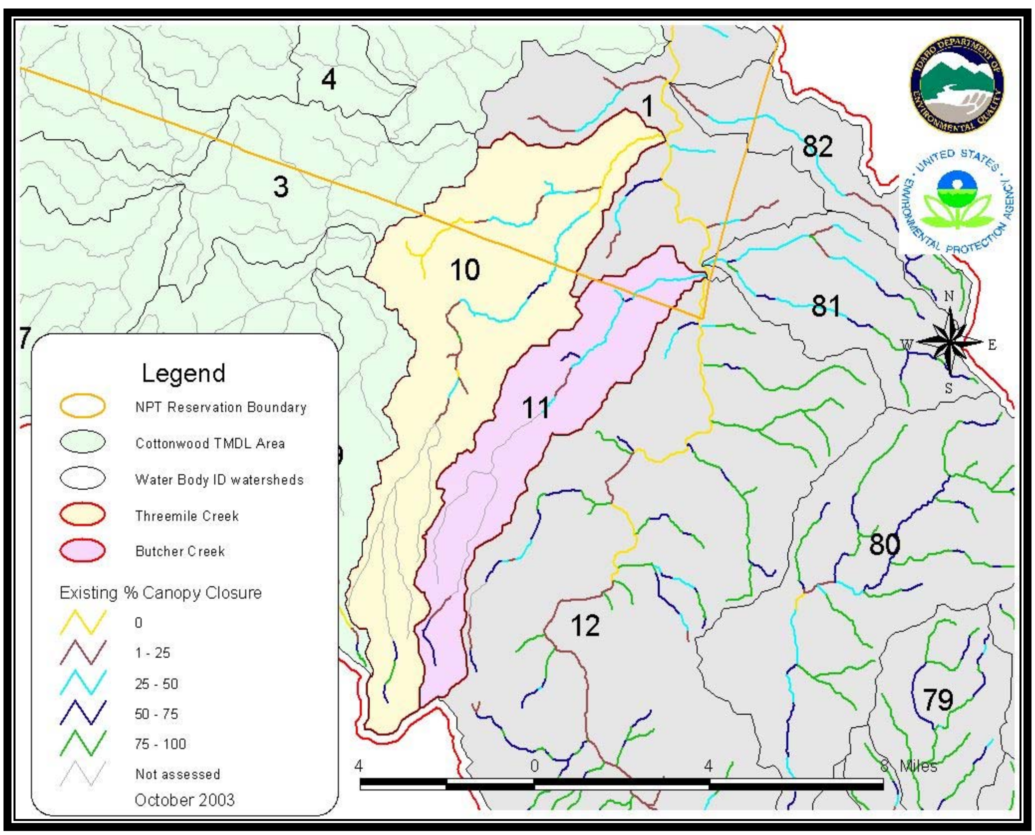

Figure G-2. Existing Percent Canopy Closure of Threemile Creek, Butcher Creek and Surrounding Streams

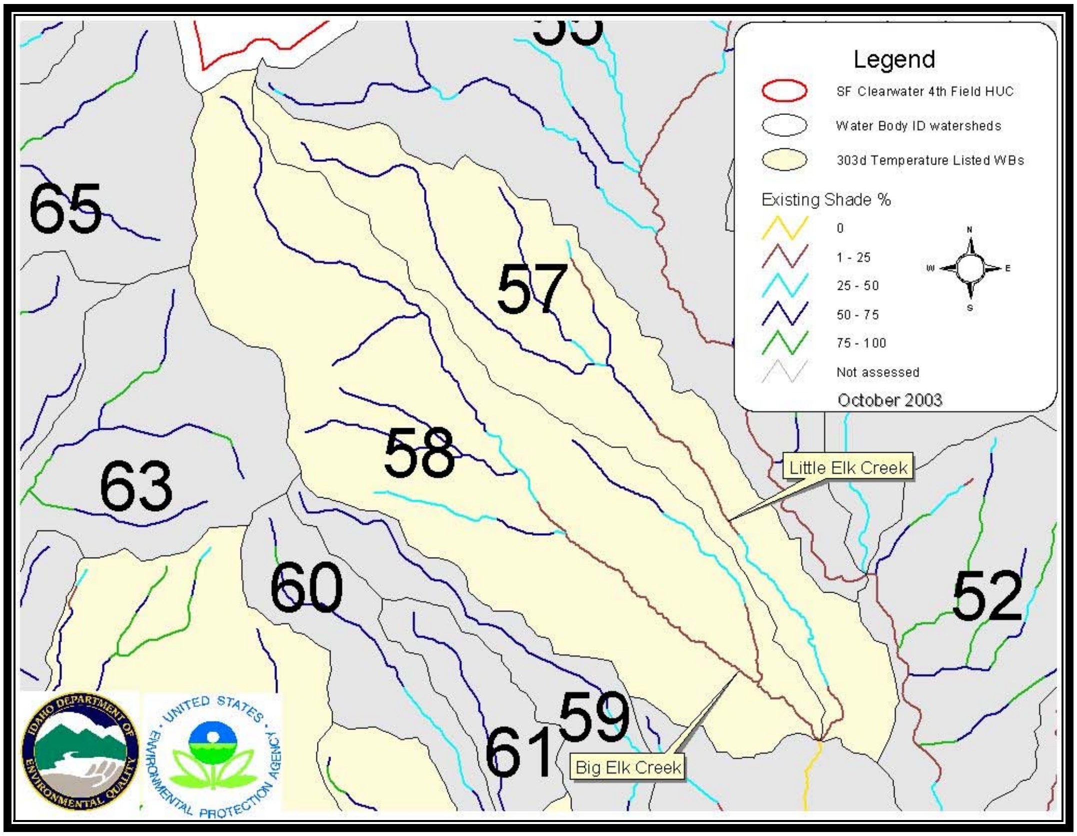

Figure G-3. Existing Percent Canopy Closure of Little Elk Creek, Big Elk Creek and Surrounding Streams

At the time of interpreting the aerial photos to determine existing percent canopy closure, we also identified areas that are meadows, hay lands, agricultural lands, or that had been dredge mined or for some other reason could not be considered related to forest practices. These areas are being analyzed using the SPV methods and are identified in the subsequent maps as such.

Figures G-4 through G-6 show the percent canopy closure that the CWE temperature model predicts is needed to protect stream temperatures. Given that the whole subbasin is being analyzed for salmonid spawning, the primary variable controlling the predicted percent canopy closure needed is elevation. The predicted needed percent canopy closure decreases regularly with elevation. Once again, we show the subbasin as a whole (Figure G-4), then the two selected areas in more detail (Figures G-5 and G-6). Any area of interest can be printed in more detail using ArcView and the enclosed ArcView shapefile.

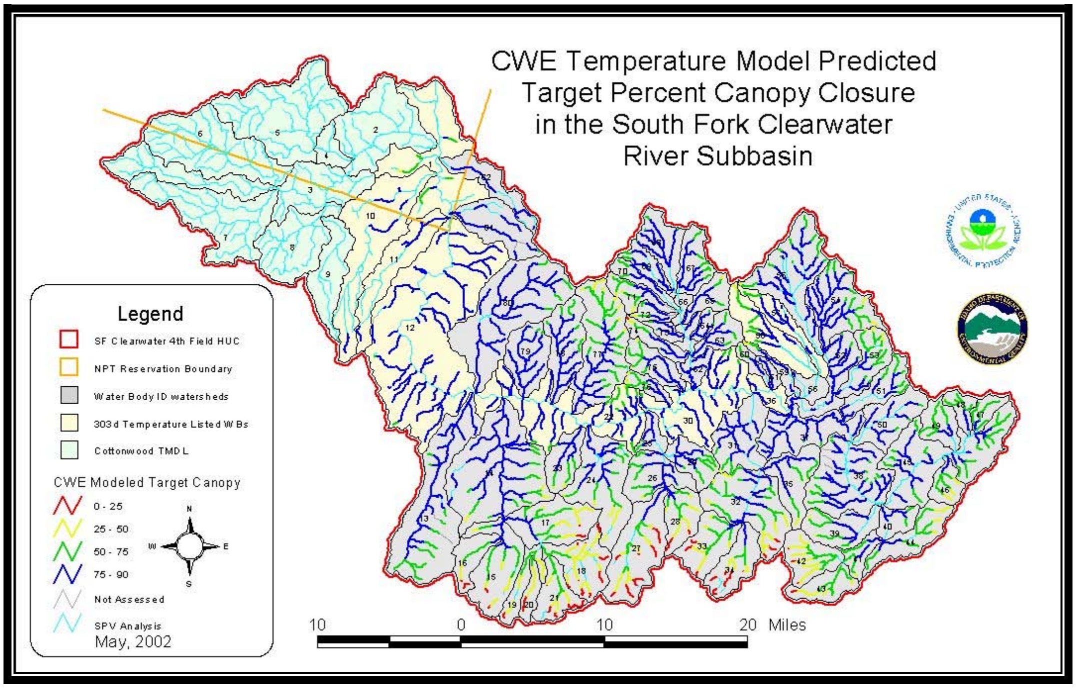

Figure G-4. Percent Canopy Closure Predicted by the CWE Temperature Model as Needed to Protect Stream Temperatures for Salmonid Spawning in the SF CWR Subbasin

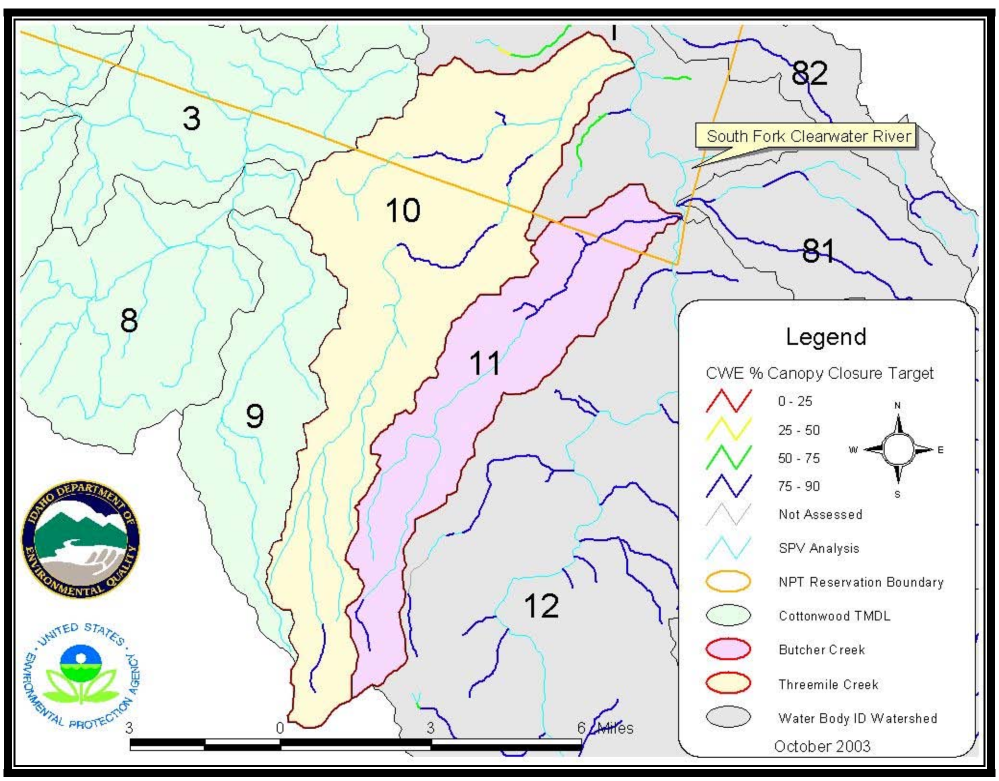

Figure G-5. Percent Canopy Closure Predicted by the CWE Temperature Model as Needed to Protect Stream Temperatures for Salmonid Spawning in the Threemile and Butcher Creeks Area

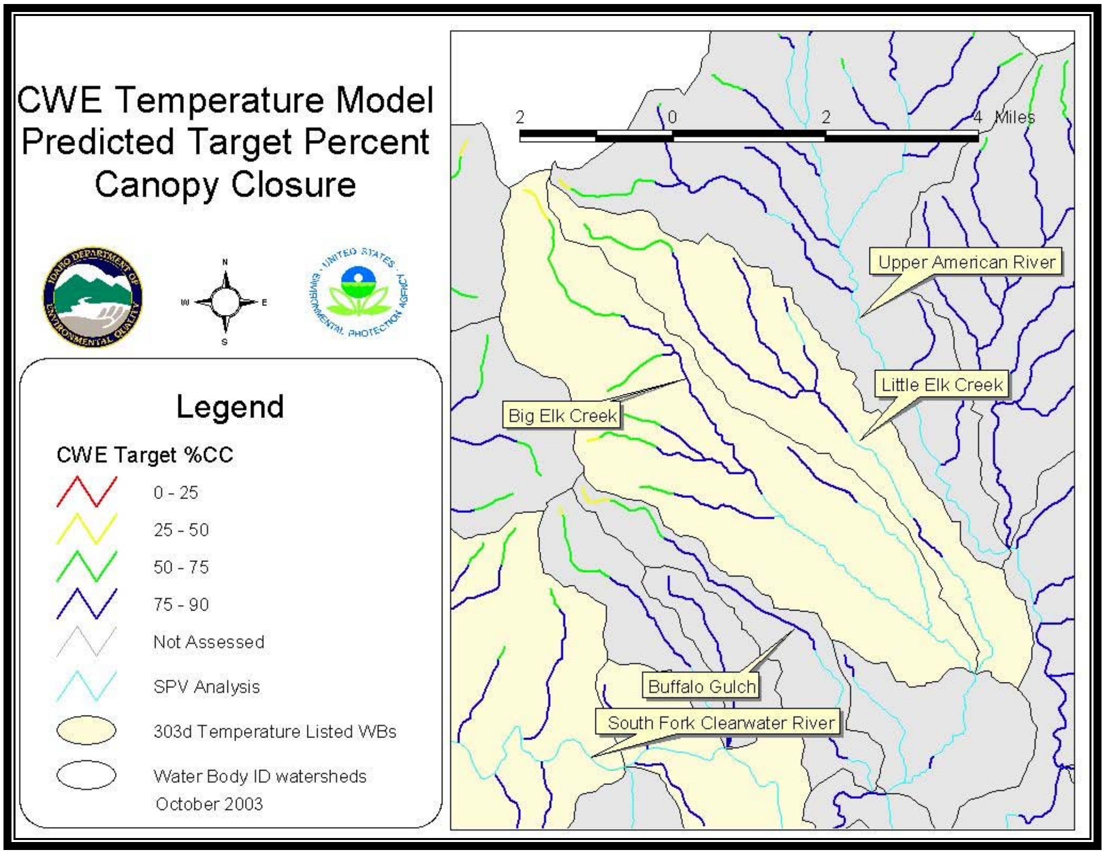

Figure G-6. Percent Canopy Closure Predicted by the CWE Temperature Model as Needed to Protect Stream Temperatures for Salmonid Spawning in the Little Elk and Big Elk Creeks Area

As noted above, USEPA determined that, as an added measure of protection of stream temperatures, TMDLs developed using the CWE temperature model should not set stream shade targets at less than existing percent canopy closure. Thus, in order to set the percent canopy closure targets for each of the stream segments, the existing percent canopy closure was compared to the CWE-predicted percent canopy closure, and the greater of the two was chosen. Figures G-7 through G-9 show the percent canopy closure targets set using the CWE model modified by the USEPA condition. The regular progression of needed percent canopy closure is broken in places where existing percent canopy is greater than that predicted as needed by the CWE temperature model.

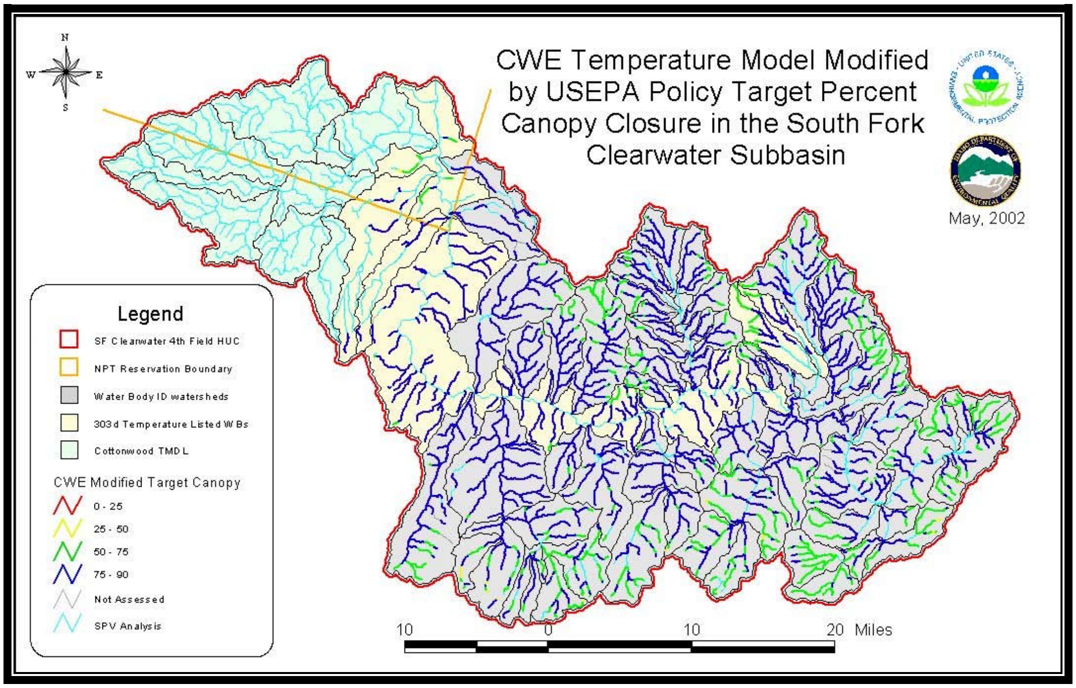

Figure G-7. Percent Canopy Closure Targets for the Forested Portions of the SF CWR Subbasin

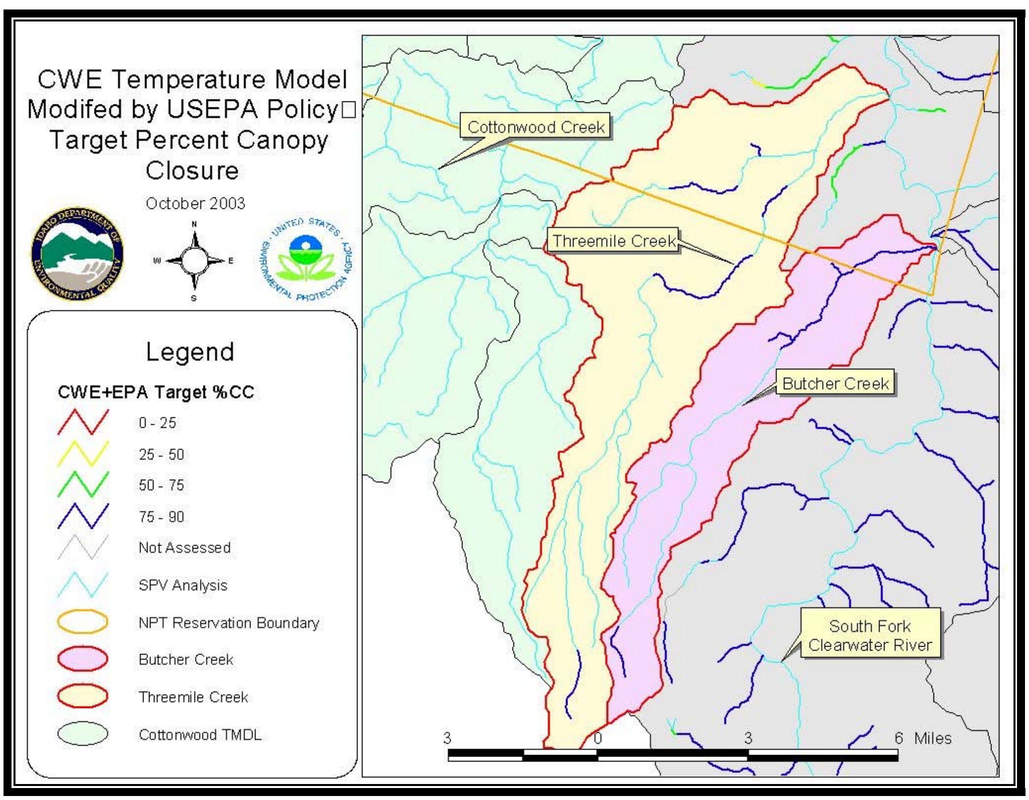

Figure G-8. Percent Canopy Closure Targets for the Forested Portions of the Threemile Creek, Butcher Creek and Adjacent Streams

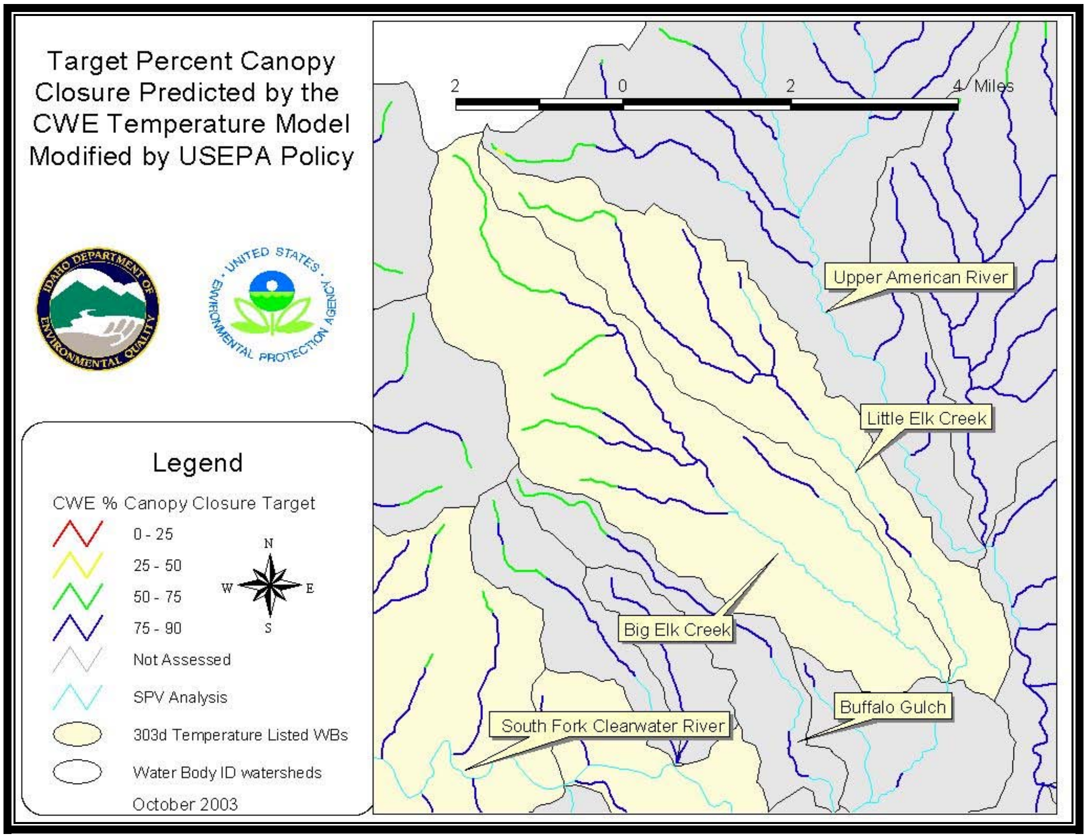

Figure G-9. Percent Canopy Closure Targets for the Forested Portions of the Little Elk and Big Elk Creeks and Adjacent Streams

Finally, in order to show the increase in percent canopy closure needed in the forested areas to be able to attain the TMDL targets, the existing percent canopy closure is subtracted from the target percent canopy closure on a stream segment by stream segment basis. The percent canopy closure increase needed is shown in Figures G-10 through G-12. These data are included in an ArcView shapefile included on diskette with this document.

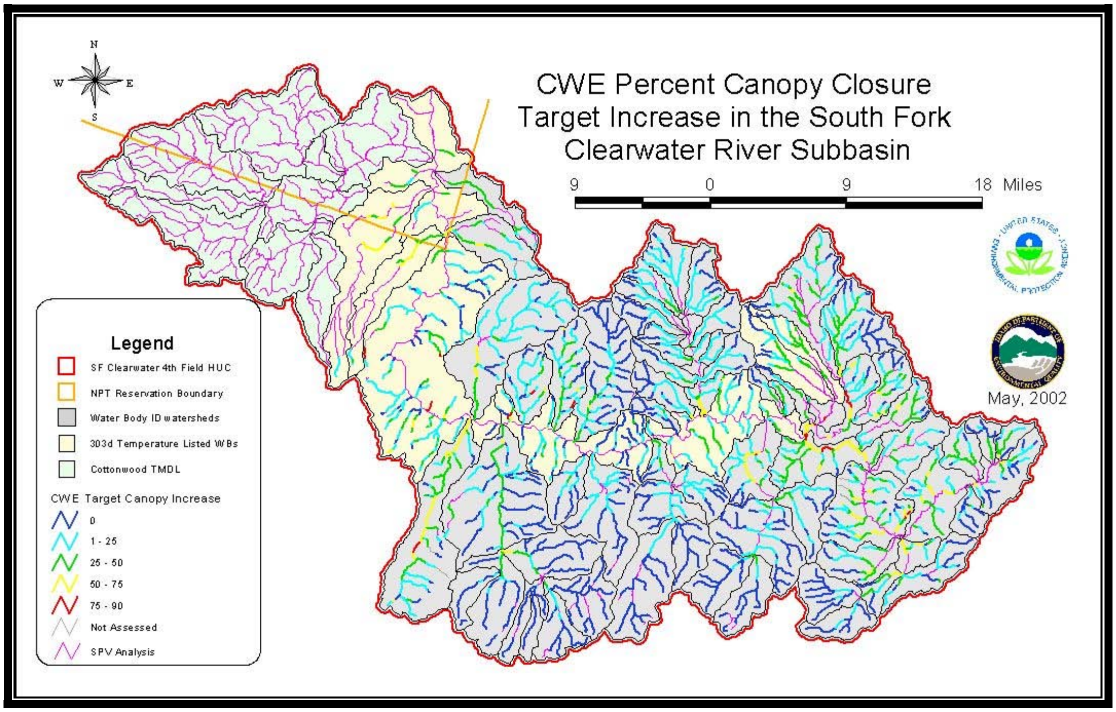

Figure G-10. Percent Canopy Closure Increase Needed in the Forested Areas of the SF CWR Subbasin

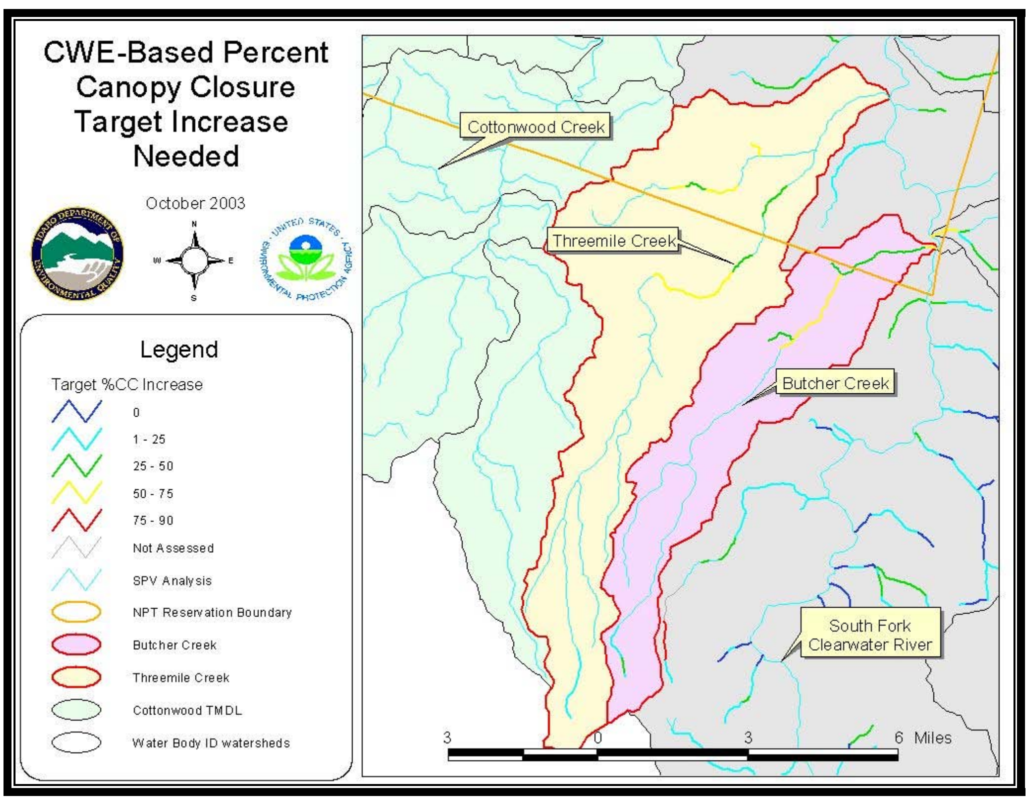

Figure G-11. Percent Canopy Closure Increase Needed in the Forested Areas of Threemile Creek, Butcher Creek and Adjacent Streams

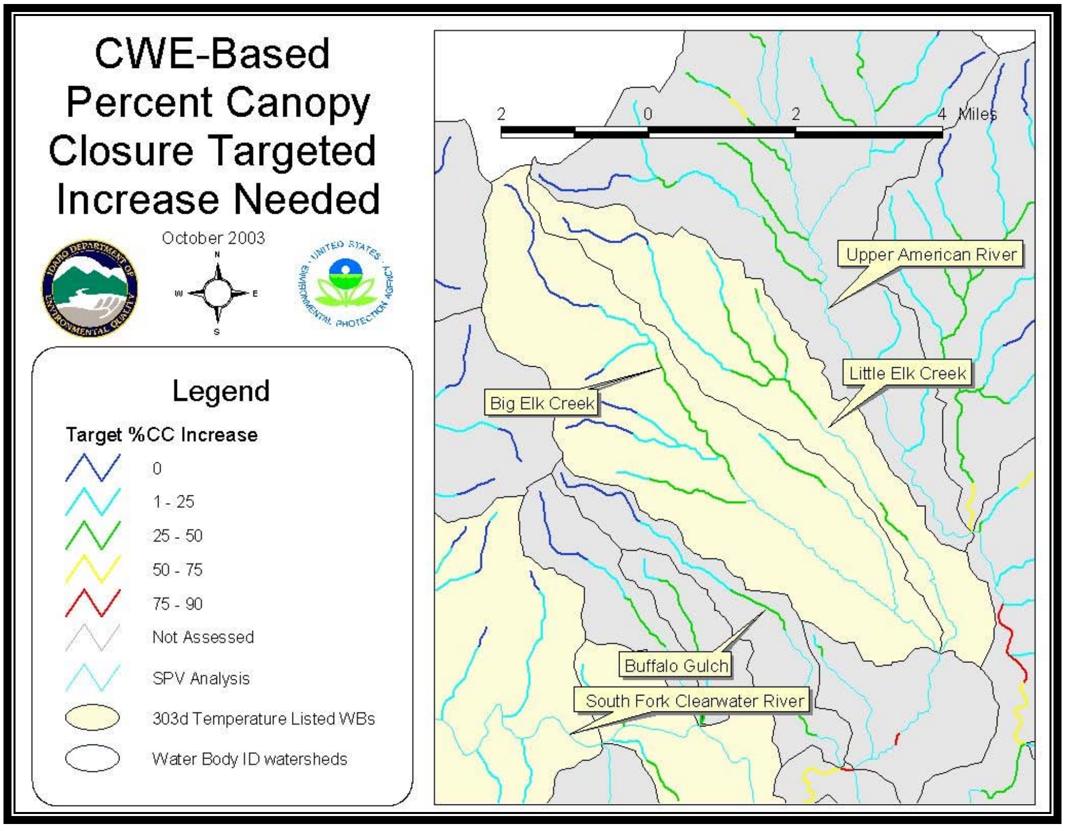

Figure G-12. Percent Canopy Closure Increase Needed in the Forested Areas of Little Elk and Big Elk Creeks and Adjacent Streams

The heat load reduction allocations presented in terms of the surrogate target, percent canopy closure, are specific to the 303(d) listed water quality limited streams. In those situations where the effects of heat loading from non-303(d) listed streams are contributing to water standard exceedances in a 303(d) listed water body, the assigned load reduction allocation, defined in terms of the surrogate target, percent canopy closure increase, has been distributed appropriately throughout the water bodies wherever percent stream canopy closure is inadequate according to the CWE analytical methods and model, modified by the USEPA conditions. This resulted in TMDLs being developed for all 82 water bodies in the SF CWR Subbasin.

Riparian areas along streams do not naturally exhibit 100% or even 90% canopy cover for the entire length of the streams. Natural events (fires, landslides, wind events) may affect riparian vegetation along small stream segments or entire streams. In addition, larger streams (Crooked River, American River, Red River, lower Johns Creek) have larger stream widths that do not allow for a high canopy closure. Also, colder habitat types typically found at high elevations or in cold air drainages often do not support 90% canopy cover. An evaluation of the densiometer field data in conjunction with the aerial photo interpretation results indicates that 90% canopy closure is approximately the greatest percent canopy closure one should expect. The surrogate targets have been set, therefore, with 90% canopy closure as the maximum possible. We have not attempted to sort out the site-specific conditions in relation to the CWE predictions where even 90% canopy closure is not possible, but leave that question for the land managers as they develop their implementation plans.

The heat load targets are the state's water quality temperature standards for salmonid spawning for the most limiting salmonid species or the federally promulgated temperature standards for bull trout. The critical time period has been determined to be the months of July and August; therefore, the targets are set for those months. If the targets are attained during July and August, when water flows are low and air temperatures are high, it is relatively certain that water quality temperature standards will be met throughout the rest of the year.

For federally protected bull trout watersheds, the target shall be 10^{o}C (50^{o}F) MWMT during the months of July and August. The list of federally protected water bodies (Appendix B) includes all the water bodies of the SF CWR Subbasin except for the main stem SF CWR, Threemile Creek, Butcher Creek, Wing Creek, Red Horse Creek, Buffalo Gulch, Maurice Creek, Sing Lee Creek, Leggett Creek, Fall Creek, Peasley Creek, and Cougar Creek. For other streams that support cutthroat trout, the target shall be 9^{o}C (48.2^{o}F) mean daily temperature for the month of July. For water bodies that support only rainbow trout, the target shall be 9^{o}C (48.2^{o}F) mean daily temperature from July 1 through July 15.

To address the concern regarding conversion of CWE results to heat loading per unit time, we take an approach of separating the effects of insolation from the other heat flux processes. The two primary environmental variables that determine stream temperature are air temperature and stream shading. Air temperature enters into the heat transfer relationships for many of the heat transfer processes associated with streams (e.g., convection, evaporation, long wave radiation), and is the primary driver of average water temperature. The CWE accounts for the variation in air temperature based on elevation. Stream shading affects the amount of solar radiation impinging on the water surface, and is the primary driver of the diurnal fluctuations in water temperature. The CWE results are in effect the change in heat loading associated with changes in stream shading.

In order to quantify heat loading to a stream surface due to insolation, we used SSTEMP (Bartholow 1997) derived data for August 1 (median hottest day) for insolation rates and calculated the heat loading for different levels of percent shade. The amounts of solar radiation incident on the stream and its immediate surroundings at different shadings for two stream orientations are presented in Table G-1. Fixed conditions used in SSTEMP to develop the solar radiation numbers are 47 degrees latitude; 5,000 feet elevation; a stream width of 10 feet; a buffer height of 60 feet; a buffer width of 30 feet; and topographic shade of 30 degrees. These are generalized standard conditions for streams of the SF CWR Subbasin. Under these conditions, incident solar radiation decreases regularly by 21 watts per square meter for every 10% increase in canopy density for north-south oriented streams and 26 watts per square meter for east-west oriented streams.

Table G-1. Average daily solar radiation incident on a stream related to canopy closure.

	Stream Orientation	
Canopy Closure (percent)	North-South (watts per square meter)	East-West (watts per square meter)
0	226	274
10	205	248
20	185	223
30	164	197
40	143	172
50	122	146
60	101	120
70	80	95
80	59	69
90	38	43
100	17	18

These heat flux amounts do not represent the total heat flux, but just the heat flux directly from the sun (insolation). This is the portion of heat flux this TMDL addresses because it is readily increased by human activities that reduce stream shading and can be managed to decrease stream temperatures. Insolation flux rates decrease linearly with increases in shading (Table G-2). Considering the CWE model above, the decrease in stream temperature due to increased percent canopy closure at a given elevation is also linear. Assuming the CWE model is correct, the linear decrease in temperature implies that the change in heat flux is constant and directly related to shading. These results indicate that the total heat flux is linearly related to the insolation rates, such that the percentage heat reduction required by the TMDL will be the same whether it is calculated from total heat flux or from insolation rates. In this TMDL, we use the CWE model with percent shade as the dependent variable directly related to insolation rates.

Table G-2. The heat loading capacities for the SF CWR in terms of CWE-derived percent stream canopy closure by elevation and associated insolation rates for the 10^{o}C MWMT regulation-defined heat loading capacity.

Elevation Zones (feet)	Percent Stream Canopy Closure (percent)	Insolation Rate North-South Oriented Stream (watts/meter^2)	Insolation Rate East-West Oriented Stream (watts/meter^2)
5,400-5,599	58	105	125
5,200-5,399	64	93	110
5,000-5,199	71	78	92
4,800-4,999	77	65	77
4,600-4,799	83	53	61
4,400-4,599	89	40	46
4,200-4,399	95	28	31
4,000-4,199	100	17	18
3,800-3,999	100 *	**	**
3,600-3,799	100 *	**	**
3,400-3,599	100 *	**	**
3,200-3,399	100 *	**	**
3,000-3,199	100 *	**	**
2,800-2,999	100 *	**	**
2,600-2,799	100 *	**	**
2,400-2,599	100 *	**	**
2,200-2,399	100 *	**	**
2,000-2,199	100 *	**	**
1,800-1,999	100 *	**	**
1,600-1,799	100 *	**	**
1,400-1,599	100 *	**	**
1,200-1,399	100 *	**	**
1,000-1,199	100 *	**	**
800-999	100 *	**	**

* Below about 4,000 feet elevation, the CWE model predicts a need for greater than 100% canopy closure to protect a maximum stream temperature of 10^{o}C MWMT. Since this is not possible, 90% canopy closure is set as the surrogate heat loading capacity. In some cases, 90% canopy closure may not be achievable because of the canopy type, in which case it should be noted in the implementation plan.

** SSTEMP predicts insolation rates of 17 or 18 watts per square meter for 100% canopy closure

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